Large-scale conservation planning in a multinational marine environment: cost matters

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Abstract. Explicitly including cost in marine conservation planning is essential for achieving feasible and efficient conservation outcomes. Yet, spatial priorities for marine conservation are still often based solely on biodiversity hotspots, species richness, and/or cumulative threat maps. This study aims to provide an approach for including cost when planning large-scale Marine Protected Area (MPA) networks that span multiple countries. Here, we explore the incorporation of cost in the complex setting of the Mediterranean Sea. In order to include cost in conservation prioritization, we developed surrogates that account for revenue from multiple marine sectors: commercial fishing, noncommercial fishing, and aquaculture. Such revenue can translate into an opportunity cost for the implementation of an MPA network. Using the software Marxan, we set conservation targets to protect 10% of the distribution of 77 threatened marine species in the Mediterranean Sea. We compared nine scenarios of opportunity cost by calculating the area and cost required to meet our targets. We further compared our spatial priorities with those that are considered consensus areas by several proposed prioritization schemes in the Mediterranean Sea, none of which explicitly considers cost. We found that for less than 10% of the Sea's area, our conservation targets can be achieved while incurring opportunity costs of less than 1%. In marine systems, we reveal that area is a poor cost surrogate and that the most effective surrogates are those that account for multiple sectors or stakeholders. Furthermore, our results indicate that including cost can greatly influence the selection of spatial priorities for marine conservation of threatened species. Although there are known limitations in multinational large-scale planning, attempting to devise more systematic and rigorous planning methods is especially critical given that collaborative conservation action is on the rise and global financial crisis restricts conservation investments.

Key words: large-scale conservation planning; marine conservation; marine protected area (MPA) network; Marxan; Mediterranean Sea; multinational conservation; opportunity cost; systematic conservation planning.

Introduction

An important and often overlooked component of marine conservation planning is the inclusion of conservation cost. Incorporating cost is necessary for delivering feasible conservation outcomes and for ensuring the successful implementation of Marine Protected Areas, MPAs (Lundquist and Granek 2005, Stewart and Possingham 2005, Ban and Klein 2009). However, cost is by no means a new concept in conservation planning. The well-known framework of systematic conservation planning enables us to incorporate cost and other social, economic, and political aspects (Pressey and Bottrill 2009, Micheli et al. 2013). Previous studies have also presented methods for integrating cost into planning for the selection of marine

conservation priorities (e.g., Klein et al. 2008, Ban et al. 2009, Klein et al. 2010, Giakoumi et al. 2011). These methods enable us to make more achievable conservation plans that improve conservation efficiency by maximizing biodiversity and reducing cost. Despite this, to date there are still numerous plans for marine reserves and priority marine conservation areas that are produced without a measure of cost (Naidoo et al. 2006, Ban et al. 2011, Micheli et al. 2013).

There are several types of cost that can be included in marine conservation planning. These include management cost (Balmford et al. 2004, Klein et al. 2010), monitoring cost (Gerber et al. 2005), transaction cost (Naidoo et al. 2006), and opportunity cost (Giakoumi et al. 2011). The most commonly accounted for and significant cost in marine planning is opportunity cost (Ban and Klein 2009). Opportunity cost is the forgone cost (or in other words, the lost benefit) when an activity takes place where another has occurred or can occur (e.g., fishing profits that are forgone when an area is made a closed/no take MPA; Cameron et al. 2008).

There are also several forms of opportunity cost to consider, including commercial and recreational activities such as diving, boating, tourism, and fishing, as well as infrastructure cost such as offshore oil and gas production (Naidoo et al. 2006). The opportunity cost that is most commonly accounted for when planning marine conservation is related to fishing (Ban and Klein 2009). Yet, few studies, if any, have attempted to deal with opportunity cost over large-scale marine environments with multiple countries characterized by high heterogeneity in data availability.

The absence of cost data within many marine conservation plans is partly due to the challenge of quantifying and incorporating this component. This is especially the case in data-poor regions, large areas, and multinational environments. One of the first hurdles is to utilize and translate data related to human economic activities into cost values (when such values are absent) for use within conservation plans. Indeed, this can be a difficult task for biologists, ecologists, and conservation planners who may have no formal education in the field of economics (Naidoo et al. 2006). Second, finding economic data that are spatially explicit can be difficult; such data are often nonexistent, especially over large-scale areas (Naidoo et al. 2006, Ban and Klein 2009). In these circumstances, we must often turn toward developing surrogates for cost (Ando et al. 1998, Ban et al. 2009, Giakoumi et al. 2011). Thirdly, other challenges emerge when we explore conservation planning across different states, national jurisdictions, or countries (Kark et al. 2009, Mazor et al. 2013). The ability to find explicit cost data that are compatible and comparable between various jurisdictions or countries with different socioeconomic status becomes more difficult. Nevertheless, as marine conservation planning begins to expand to larger spatial scales for the development of marine protected networks that encompass several countries (Miclat et al. 2006, Douvere 2008), we cannot ignore cost, the socioeconomic context in which our biodiversity goals exist (Polasky 2008).

Mediterranean Sea conservation planning

Large-scale conservation plans are arising in the marine realm, particularly for waters shared by multiple countries, such as the Mediterranean Sea (e.g., Notarbartolo di Sciara and Agardy 2009, CIESM 2011, Oceana 2011). The multiple number of large-scale plans for the Mediterranean Sea that have recently emerged focus mostly on identifying priority areas for protecting threatened species or habitats that span across multiple countries (Micheli et al. 2013). Yet, no large-scale conservation plans for the Mediterranean Sea have explicitly included cost (Giakoumi et al. 2012b, Micheli et al. 2013). Only several small-scale Mediterranean studies have addressed the cost of marine conservation within the framework of systematic conservation planning (Fraschetti et al. 2009, Maiorano et al. 2009, Giakoumi et al. 2011, 2012a). Large-scale planning is

important for the Mediterranean Sea (Portman et al. 2013), but without incorporating cost, the ability of plans to aid decision makers can only go so far. To better direct and inform decision makers, there is a need for systematic methods that are driven by explicit objectives and translate into actions and costs (Margules and Pressey 2000, Moilanen et al. 2009).

The Mediterranean Sea supports the livelihood of millions of people via the exploitation of its living marine resources (Abdulla et al. 2008, Madau et al. 2009). The gross value of marine resources from lagoon and marine fishing and aquaculture in Mediterranean countries was estimated at US$6.3 billion for 2008 (Sacchi 2011). Fishing also has a great social and cultural value for most Mediterranean countries (Farrugio et al. 1993; see Plate 1). Therefore, when we aim to protect biodiversity in the Mediterranean Sea, we must take into account the importance of this prevalent economic and cultural activity. A possible reason that this has never been accounted for at a whole-basin scale before is that the Mediterranean Sea is a collection of different countries with huge differences in socioeconomic status, political regimes, languages, governance, and cultures (Badalamenti et al. 2000, Giakoumi et al. 2012b). A major challenge is the standardization of data at a basin level, because there is a striking imbalance of available information. Data availability itself presents a challenge, as there is a negative gradient from the north to the south as well as from the west to the east of the Mediterranean Basin (Abdulla et al. 2008, Coll et al. 2012, Micheli et al. 2013).

Here, we aim, for the first time at the scale of the whole Mediterranean Sea, to explicitly account for cost in conservation planning. We develop an approach for incorporating opportunity cost of exploitation of marine resources at large spatial scales within heterogeneous systems. We address three major sectors of marine exploitation: commercial fishing (including industrial and artisanal fishing), noncommercial fishing (recreational and subsistence), and aquaculture. Our objective is to provide an approach that allows one to include cost when planning large-scale MPA networks that span multiple countries. We aim to explore how the explicit consideration of cost alters conservation priority areas across the Mediterranean Sea. Furthermore, we will compare our results with consensus areas of 12 Mediterranean prioritization schemes that did not account for cost (Micheli et al. 2013).

METHODS

Spatial extent and species information

Our study area comprised the entire Mediterranean Sea. We divided the area into 10×10 km planning units (26 946 in total). This resolution was chosen to comply with the EU guidelines on the use of a Pan-European grid of 10×10 km for spatial planning (Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial

PLATE 1.   Jaffa Port (Israel)—an historical commercial fisheries port of the Mediterranean Sea, active for over 7000 years. Photo credit: T. Mazor.

Information in the European Community [Inspire]) and based on our previous work in the Mediterranean Basin (Kark et al. 2009, Mazor et al. 2013).

Spatial distribution data were available for 77 threatened marine vertebrate species in the Mediterranean Sea. These included marine fishes, sharks and rays, marine mammals, sea birds, and sea turtle nesting sites (Appendix A: Table A1; see IUCN 2012). We projected all available species data into Albers Equal Area Projection at the planning unit scale, using ArcGIS software (Appendix A: Fig. A1).
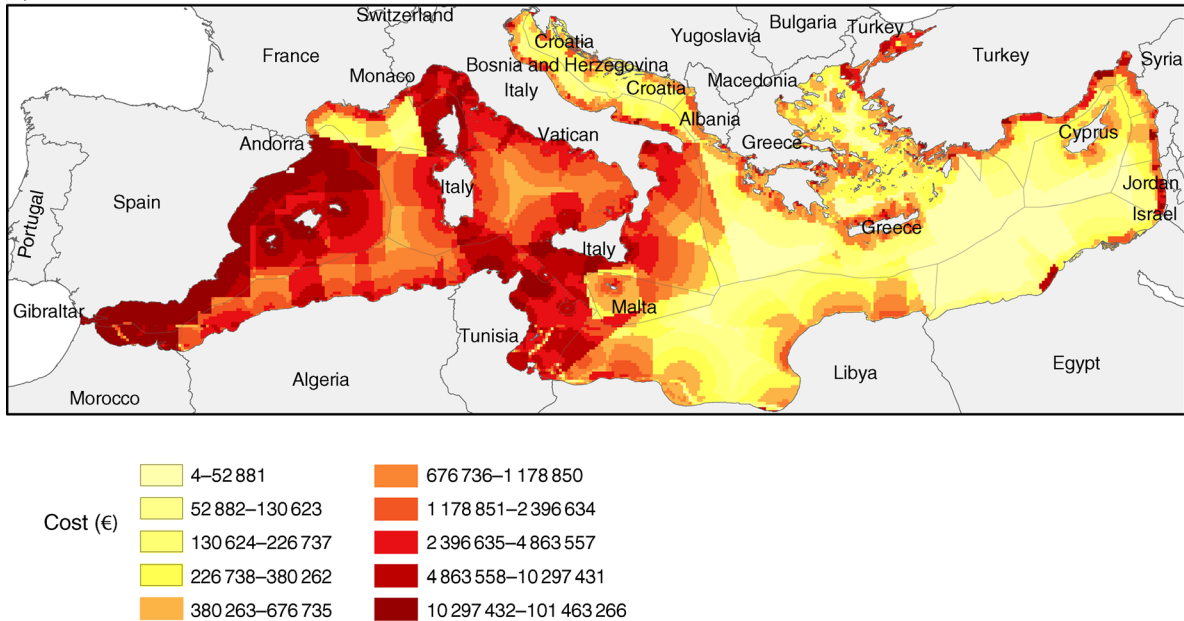
Opportunity cost surrogates

We derived surrogate cost layers to represent the opportunity cost (cost of establishing an MPA in a given area) of different marine sectors including fisheries and aquaculture activities. The three sectors included were: commercial (both industrial and artisanal) fishing, noncommercial (recreational and subsistence) fishing, and aquaculture. For each of these three sectors we developed equations to calculate opportunity cost in monetary terms (€) for each planning unit (Fig. 1). We used these opportunity cost layers separately or in combination (summed together) to give a total of nine

scenarios of cost (see Table 1). These scenarios were used to quantify the benefit of planning conservation by using area (area of planning unit) as a cost and including single vs. multiple sectors cost. Each opportunity cost layer in these scenarios will be described.

Commercial fishing layers.—Here we developed two different cost layers to represent the opportunity cost of commercial fishing, using data provided from two different sources (Appendix B: Fig. B1). The first cost layer is based upon biomass of fish caught over 28 different geographical regions, data provided by the General Fisheries Commission for the Mediterranean, GFCM (FAO 2011). The second cost layer uses fish landings in monetary values for 22 counties, with data provided by the Sea Around Us Project, SAUP (Sea Around Us Project 2011).

GFCM cost layer.—The opportunity cost of commercial fishing was calculated as the combined cost of (1) small-scale fishing that occurs close to the coast and (2) large-scale fishing in deeper waters (for full methods, see Appendix B: Table B1). To calculate the opportunity cost of this sector, we developed an equation (a simplified approach was used in Mazor et al. 2013) where C_i is the annual value, and thus
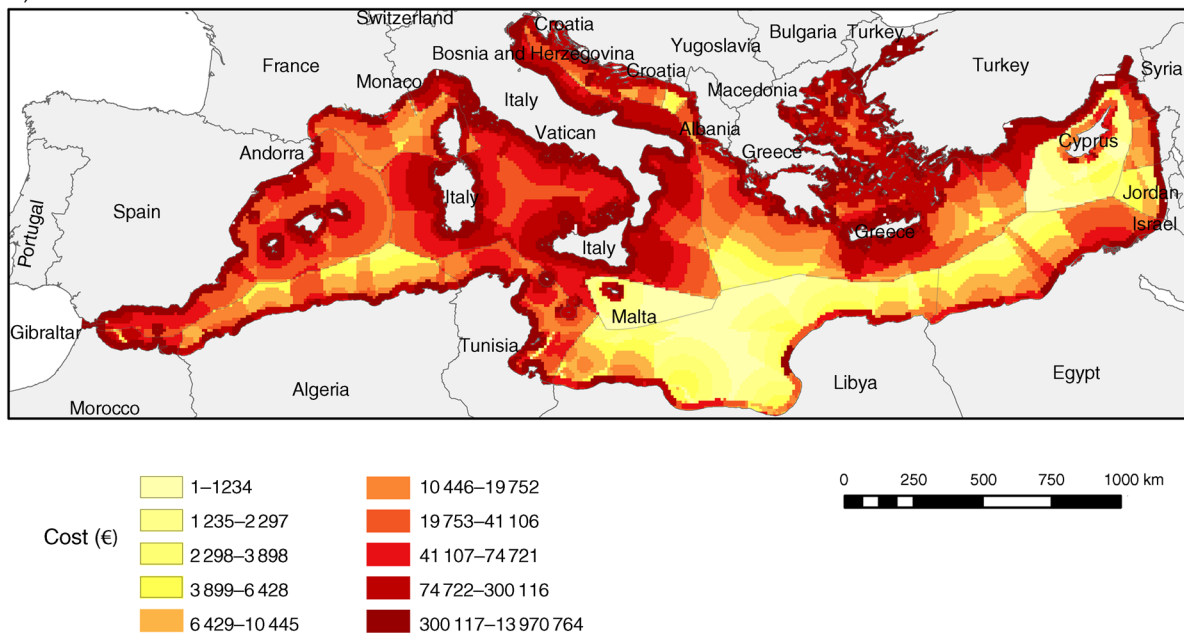
a) Scenario 6

Cost (€)

4–52 881	676 736–1 178 850
52 882–130 623	1 178 851–2 396 634
130 624–226 737	2 396 635–4 863 557
226 738–380 262	4 863 558–10 297 431
380 263–676 735	10 297 432–101 463 266

b) Scenario 7

Cost (€)

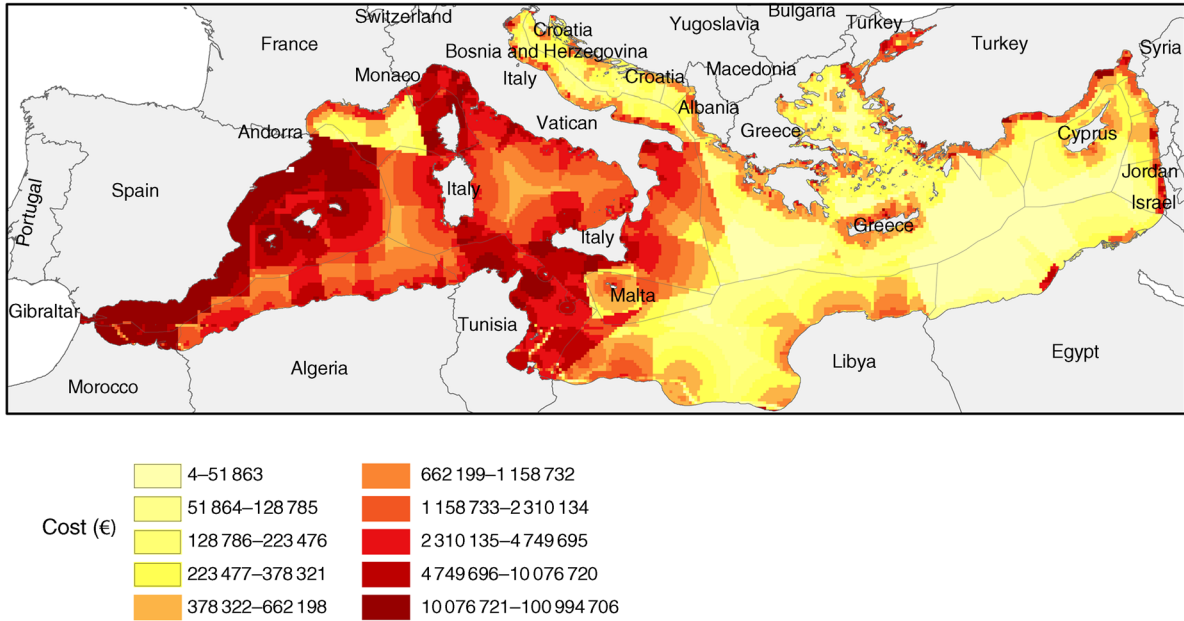|	
1–1234	10 446–19 752
1 235–2 297	19 753–41 106
2 298–3 898	41 107–74 721
3 899–6 428	74 722–300 116
6 429–10 445	300 117–13 970 764

0   250   500   750   1000 km

FIG. 1. The final combined sector cost layers (opportunity cost in € displayed by a quantile range) when all marine sectors (commercial, noncommercial, and aquaculture) in the Mediterranean Sea are combined: (a) combined sectors A (scenario 6), (b) combined sectors B (scenario 7), (c) combined sectors C (scenario 8), and (d) combined sectors D (scenario 9). See Table 1 for scenario details. Opportunity cost is the cost of establishing a marine protected area (MPA), measured as lost income from restricting fishing and aquaculture in the conservation area. The quantile range divides the range of possible values into unequal-sized intervals so that the number of values is the same in each class.

opportunity cost of commercial fishing in each planning unit i. We assumed that the opportunity cost is proportional to the size of the nearest port, PS (for port sizes, see National Geospatial-Intelligence Agency

2005), and decreases exponentially with distance d from port weighted exponentially by a constant ∝ (0.01) and the area A of planning unit i. We used annual tonnage data regarding total fishing from 28
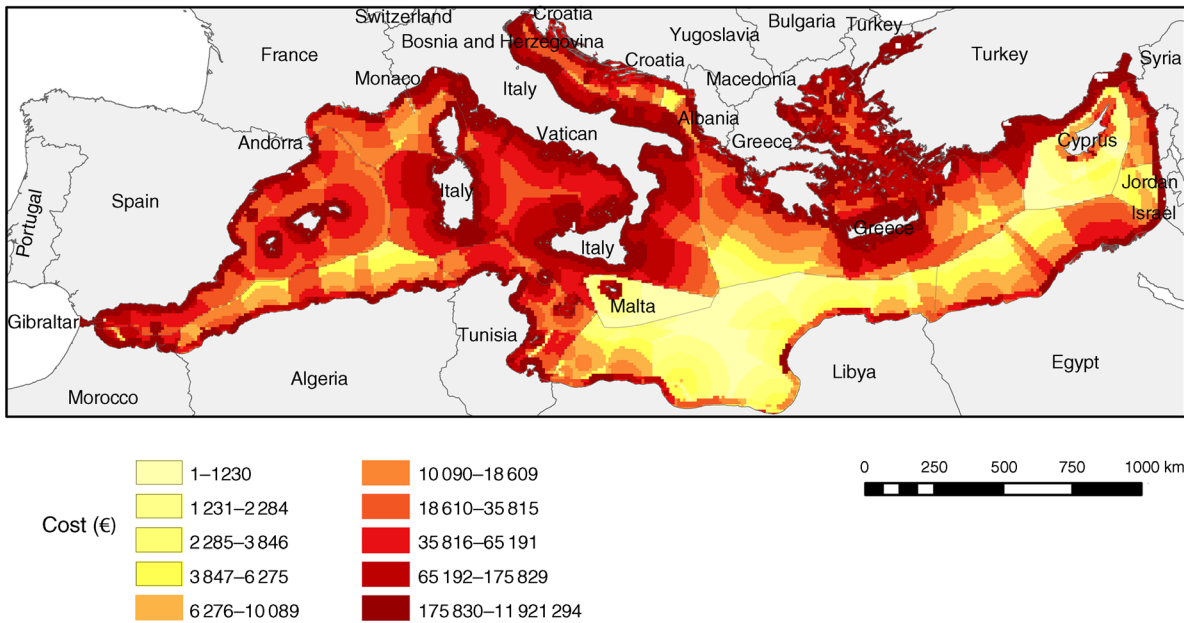
c) Scenario 8

Cost (€)	
4–51 863	662 199–1 158 732
51 864–128 785	1 158 733–2 310 134
128 786–223 476	2 310 135–4 749 695
223 477–378 321	4 749 696–10 076 720
378 322–662 198	10 076 721–100 994 706

d) Scenario 9

Cost (€)	
1–1230	10 090–18 609
1 231–2 284	18 610–35 815
2 285–3 846	35 816–65 191
3 847–6 275	65 192–175 829
6 276–10 089	175 830–11 921 294

FIG. 1. Continued.

Geographical Sub-Areas (GSAs) as reported by the General Fisheries Commission for the Mediterranean GFCM for 2008 (FAO 2011). This is the most current, spatially available data for the entire Mediterranean Sea on fish catch. To ensure that the total value of catch in each region (28 GSA regions) sums to its real value, we normalized the cost of commercial fishing in each planning unit by a measure of total regional effort E_R:

$$E_R = \sum_{i=1}^{m} \mathrm{PS}\ e^{-\alpha d} A_i$$

where m is the number of planning units in a given region. We multiplied the final value by the total production of fish in the region (in metric tons) B_R, multiplied by the value of fish (€ per metric ton) V_{fish},

TABLE 1. Nine opportunity cost scenarios (the lost revenue of sectors from establishing an MPA in a given area) used in this study of conservation planning in the Mediterranean Sea.

Opportunity cost	Scenario name	Opportunity cost layers included in scenario (summed layers)
Scenario 1	area as cost	area of planning unit (km²)
Scenario 2	commercial fishing GFCM	commercial fishing GFCM (General Fisheries Commission for the Mediterranean; FAO 2011)
Scenario 3	commercial fishing SAUP	commercial fishing SAUP (Sea Around Us Project 2011)
Scenario 4	noncommercial fishing A	noncommercial fishing A (cost of expenditure parameter $\alpha = 0.5$)
Scenario 5	noncommercial fishing B	noncommercial fishing B (cost of expenditure parameter $\alpha = 1.0$)
Scenario 6	combined sectors A	commercial fishing GFCM + noncommercial A ($\alpha = 0.5$) + aquaculture
Scenario 7	combined sectors B	commercial fishing SAUP + noncommercial A ($\alpha = 0.5$) + aquaculture
Scenario 8	combined sectors C	commercial fishing GFCM + noncommercial B ($\alpha = 1.0$) + aquaculture
Scenario 9	combined sectors D	commercial fishing SAUP + noncommercial B ($\alpha = 1.0$) + aquaculture

such that the final expression for an estimate of the opportunity cost for commercial fishing C_i in each planning unit i is

$$C_i = \left(\frac{\text{PS } e^{-\alpha d}A_i}{E_R}\right)V_{\text{fish}}B_R.$$

For *small-scale (artisanal) commercial fishing*, we included data on the tonnage of fish extracted via small-scale vessels without engines (vessels < 12 m long), small-scale vessels with engines (>6 m and 6–12 m long) and polyvalent (i.e., multipurpose) vessels (>12 m long) (FAO 2011). Boat length was not considered an absolute criterion because in most countries, polyvalent vessels longer than 12 m that use longline and gillnet fishing can be considered as practicing artisanal fishing (Sacchi 2011). The total value was multiplied by the average price ($V_{\text{fish}} = 12.61$ €/kg for 2010; prices *available online*)[4] of five fish species (*Mullus surmeletus, Sparus aurata, Serranus cabrilla, Scorpaena scrofa, Sarda sarda*) that compose the majority of artisanal fisheries catch as reported by Lloret and Font (2013). Although the catch composition may vary throughout the Mediterranean Sea, we consider that the average value of the estimated fish catch is representative for most Mediterranean countries. Small-scale commercial fishing takes place within a country's 12 nautical mile territorial waters (IEEP 2002, Morales-Nin et al. 2005); therefore, we only included planning units (8964 planning units) that were between the coastline and a distance of 22 km (~12 nautical miles).

For *large-scale (semi-industrial and industrial) commercial fishing*, we calculated the total tonnage of large-scale commercial fishing vessels in 2008 as reported by the FAO (2011). We used the price of five fish species that are major species targeted in commercial fishing (Lleonart and Maynou 2003, European Commission 2008) in the Mediterranean Sea and relate to four particular fishing gear types: trawlers and dredgers (*Merluccius merluccius*, $V_{\text{fish}} = 7.02$ €/kg; Garcia-Vazquez et al. 2011); purse seiners and pelagic trawlers (>6 m long) (*Engraulis encrasicolus* and *Sardina*

pilchardus, average $V_{\text{fish}} = 2.38$ €/kg; FAO 2010); long-liners (>6 m long) (*Xiphias gladius*, $V_{\text{fish}} = 5.40$ €/kg; FAO 2010); and tuna seiners (<12 m long) (*Thynnus thynnus*, $V_{fish} = 17.25$ €/kg; FAO 2010).

SAUP cost layer.—Here we used data provided by the Sea Around Us Project (SAUP) on annual landings (US$ per ton) for each county (22 countries) surrounding the Mediterranean Sea for the year 2006 (Sumaila et al. 2007, Sea Around Us Project 2011). These data are the most current, available data for the entire Mediterranean Sea reporting monetary values of fish landings at the country level. We assume here that each country's landings are from its own Exclusive Economic Zone, EEZ (as defined by VLIZ 2012), although a small amount of this catch may come from nearby geographical areas due the lack of supervision across marine boarders or permission from other countries to fish in their waters (FAO 2011). We use an equation similar to that in the previous cost layer by assuming that the opportunity cost is proportional to the size of the nearest port, decreases exponentially with distance, and is weighted by area. However, here we divided this by a country effort, E_C, rather on a regional effort. Also, because we have the value of the annual landings (US$) per country we multiplied our effort by the reported value V of each country. Thus, the opportunity cost for commercial fishing C in each planning unit i is defined as:

$$C_i = \left(\frac{\text{PS } e^{-\alpha d}A_i}{E_C}\right)V$$

where

$$E_C = \sum_{i=1}^{m} \text{PS } e^{-\alpha d}A_i.$$

To make our opportunity cost layer comparable to other cost layers, we converted our resulting values from U.S. dollars to Euros using the average annual exchange rate for the year 2006 as reported by the International Monetary Fund (*available online*).[5]

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[4] http://en.fishprices.net/home

[5] http://www.imf.org/external/np/fin/ert/GUI/Pages/CountryDataBase.aspx

Noncommercial fishing layers.—Here we developed an equation where C_{Ni} is the annual value (thus opportunity cost) of noncommercial fishing in each planning unit i. We summed the cost of expenditure of fishing per year C_{exp} with the value of catch V_{catch}. The C_{exp} was used to estimate the value that recreational fishers give to recreational fishing through their purchases in the related markets, e.g., recreational vessel purchases and recreational fishers participating in this activity through their revealed preference (hedonic method; see Gaudin and De Young 2007). The V_{catch}, which can be considered a benefit increasing the value of the recreational fishing, was calculated by multiplying the number of fishing days per year, the total number of kilograms of fish per day, and the value of fish (€ per kilogram). Because the cost of recreational fishing includes both V_{catch} and C_{exp}, it may be argued that one of these is more or less important than the other for determining the value of recreation fishing. Therefore, we introduce parameter α, where $0 \le \alpha \le 1$, to allow us to test different weightings. The resulting value is multiplied by the number of fishers per year N_f. The opportunity cost for noncommercial fishers per planning unit i is

$$C_{Ni} = \sum (\alpha C_{exp} + (1-\alpha)V_{catch})N_{fi}$$

and the number of fishers per planning unit, where SS is settlement size, is equal to

$$N_{fi} = \left(\frac{SS\, e^{-\alpha d} A_i}{E_R} \right) N_{fR}$$

where

$$E_R = \sum_{i=1}^{m} SS\, e^{-\alpha d} A_i.$$

We assume that opportunity cost is proportional to the size of the nearest settlement, SS (using 2011 data from Columbia University's Center for International Earth Science Information Network, *available online*),[6] and that it decreases exponentially with distance d from the settlement by a constant α and the area A of planning unit i. Due to the unavailability of data for noncommercial fishers per country, we used surrogates. In our study, C_{exp} was 1376 € (Ünal et al. 2010) and was adjusted for each country based on purchasing power parity (PPP) rates reported by The World Bank (*available online*).[7] Conversion from US$ to Euro was via the average annual exchange value for 2010 by the IMF). For V_{catch}, we used a constant of 60 fishing days per year (Ünal et al. 2010) and multiplied this by 5 kg per day which is the maximum allowed mass in most Mediterranean countries (Gaudin and De Young

2007). We used the price of 5.95 €/kg, which is the average price of 10 fish species that compose 99% of the recreational catch, as reported by Tunca et al. (2012). Two values, 0.5 and 1.0, were used for α, thus producing two cost layers for noncommercial fishing: noncommercial fishing A and noncommercial fishing B, respectively (Appendix B: Fig. B2). For N_f, we used a method used by Mazor et al. (2013), assuming that 10% of the population goes fishing (CFCM 2010, Ünal et al. 2010, Herfaut et al. 2013). We also limited our spatial extent to planning units within 12 nautical mile territorial waters, as performed in the small-scale commercial fishing layer, giving a total of 8964 planning units in our layer.

Aquaculture layer.—To spatially represent the cost of aquaculture in the Mediterranean Sea, we used data from Trujillo et al. (2012). This is currently the best available data that exist for aquaculture locations in the Mediterranean Sea. Here we calculated the area (in square kilometers) occupied by aquaculture pens, A_{AQ}, in each country using ArcGIS software (ESRI 2010). This was further divided by the sum of each country's total surface area A_{AQC} dedicated to aquaculture. The resulting value was then multiplied by the annual aquaculture production P_{AQ} (in metric tons) in 2006 as reported by Trujillo et al. (2012) for each country. To retrieve monetary values, for each country we multiplied its production P by the cost C of the two primary aquaculture species in the Mediterranean: seabream *Sparus aurata* (4.25 €/kg; FAO 2010) and seabass *Dicentrarchus labrax* (4.75 €/kg; FAO 2010, Trujillo et al. 2012). Following Trujillo et al. (2012), we have excluded tuna cages due to the relatively small number of cages in the Sea and because their productivity success is not well established in this region. The overall equation for estimating the opportunity cost for aquaculture C_{AQ} in each planning unit i is

$$C_{AQi} = \frac{A_{AQ}}{\sum A_{AQC}} PC.$$

To validate our resulting cost surrogate for the year 2006, we compared our results with those of the closest year we could find, reported in 2008 by FAO (Sacchi 2011; see Appendix B: Table B2). Our resulting cost layer is similar to that of 2008 and seems to be an underestimation rather than an overestimation of aquaculture production (Appendix B: Table B2).

Systematic conservation planning using Marxan

For the identification of priority areas in our study, we used a systematic conservation planning tool, Marxan (Ball et al. 2009). Marxan uses a simulated annealing algorithm to solve the problem of meeting biodiversity targets for the least cost. Here we set a target to protect 10% of each of 77 threatened marine species (following Mazor et al. 2013). This target was set as a realistic, achievable target for the region, consid-

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[6] http://sedac.ciesin.columbia.edu/data/set/grump-v1-settlement-points

[7] http://data.worldbank.org/indicator/NY.GNP.PCAP.PP.CD

TABLE 2. Results from Marxan best solution outputs (best solution from 1000 Marxan runs) for nine scenarios of opportunity cost.

| | Marine exploitation sectors | | | | |
| | Commercial fishing | | Noncommercial fishing | | |
Scenarios of opportunity cost	GFCM	SAUP	A ($\alpha = 0.5$)	B ($\alpha = 1$)	Aquaculture
Scenario 1. Area as cost	11.87%	10.48%	15.88%	15.92%	7.83%
Scenario 2. Commercial fishing GFCM	*1.05%*	10.49%	3.41%	3.26%	5.72%
Scenario 3. Commercial fishing SAUP	11.45%	*1.89%*	11.59%	11.57%	6.32%
Scenario 4. Noncommercial fishing A† ($\alpha = 0.5$)	1.86%(4.18%†)	2.22%(4.69%†)	*1.01%*	0.99%	8.19%
Scenario 5. Noncommercial fishing B† ($\alpha = 1$)	1.84%(4.14%†)	2.21%(4.67%†)	1.01%	*0.96%*	6.54%
Scenario 6. Combined sectors A (GFCM + noncommercial A + aquaculture)	*0.96%*	4.99%	*0.95%*	2.01%	*0.02%*
Scenario 7. Combined sectors B (SAUP + noncommercial A + aquaculture)	4.22%	*2.36%*	*0.07%*	0.06%	*0%*
Scenario 8. Combined sectors C (GFCM + noncommercial B + aquaculture)	*0.98%*	5.05%	2.37%	*2.27%*	*0.01%*
Scenario 9. Combined sectors D (SAUP + noncommercial B + aquaculture)	8.36%	*2.35%*	0.12%	*0.11%*	*0%*

Notes: Each scenario is compared by the percentage of cost the sector will lose from its annual revenue in order to implement the best solution and the surface area (%) that the solution will take up in the Mediterranean Sea. Values in italic are marine exploitation sectors that were minimized in the scenario.

† For these cost layers, 8964 planning units were used, within 22 km (~12 nautical miles) of the coastline, i.e., territorial waters. For all other cost layers, there were 26 946 10 × 10 km planning units in total.

ering that so little has been done in the Mediterranean Sea (Giakoumi et al. 2012b). However, given that these species are threatened, targets should ideally be set higher. We also ran our analysis with a 30% target for each species. Our objective was to meet targets for the minimum opportunity cost. To enable comparison between our different types of cost, we did not preferentially cluster our planning units (the Boundary Length Modifier was set to 0). We performed a Marxan analysis with 1000 runs on each of the eight opportunity cost scenarios. Our resulting Marxan outputs from each scenario were compared by analyzing the selection frequency (number of runs in which a planning unit was selected among the 1000 runs) and single best solution outputs (the solution that best reaches targets and minimizes cost). For all combined scenarios (scenarios 6–9; Fig. 1), we ran a Spearman's rank correlation on the selection frequency outputs to test how similar the outputs were.

Comparing our spatial priorities with consensus conservation areas

Here, using ArcGIS (ESRI 2010), we compared our resulting priority areas, which are the first attempt at explicitly including cost at a whole-basin scale, with those that have been recently proposed as conservation consensus priority areas in the Mediterranean Sea (Micheli et al. 2013). These consensus areas are areas where 12 proposed prioritization schemes for the Mediterranean Sea overlap (for further information, see Micheli et al. 2013). Because these consensus areas do not aim to meet biodiversity targets or build a representative reserve network, we used spatial overlap as a means of comparison. The comparison was made by calculating the percentage of overlap of our spatial priorities (planning units that had a selection frequency

> 50%) in our outputs from the most plausible combined scenarios, scenario 8 (combined sector C) and scenario 9 (combined sector D), with the consensus areas. The opportunity cost scenarios used for this comparison were chosen because they represent all sectors of marine exploitation and include the two different approaches for estimating commercial fishing.

RESULTS

Comparing opportunity cost scenarios

Our results indicate that ~10% of surface area of the Mediterranean Sea is required to implement a solution that meets our 10% conservation target (Table 2). When we increased our target to 30% for each species, we found that ~30% of Mediterranean Sea surface area is required to be protected (Appendix C: Table C1). Similarly, the cost also increased with a higher target for each scenario. For the four combined cost scenarios (scenarios 6–9), we can meet a 10% target for a cost less than 1% (for minimized sectors), whereas a cost of 3–6% is needed to reach a 30% target. Despite the area and cost requirements, we found that the relative changes in cost were similar for the scenarios under the different targets (Table 2; Appendix C: Table C1). Due to this, the following results will discuss only the 10% target.

We found that the total cost and area were the lowest when multiple marine sectors were included in the opportunity cost (scenarios 6–9; Table 2, Fig. 2). Although scenarios that included only one marine sector (scenarios 2–5) incurred higher costs and area than combined scenarios, they all performed better than using area as a cost surrogate (scenario 1). The combined sector scenarios had a total cost of 1.1–3.73%, single sector scenarios between 3.85% and 8.67%, and area of 12.25% (Table 2). In all cases in which opportunity cost

TABLE 2. Extended.

Cost of all sectors	Cost of minimized marine sectors (area)	Area of the Mediterranean Sea
12.25%	9.99%	11.48%
8.67%	1.05%	9.82%
5.42%	1.89%	10.25%
2.01%(3.92%†)	1.01%	3.40% (10.22%†)
1.96%(3.85%†)	0.96%	3.44% (10.34%†)
1.10%	0.89%	9.54%
3.73%	0.33%	9.51%
1.14%	0.92%	9.58%
3.71%	0.46%	9.53%

from a particular marine sector was included in the scenario, we found that the percentage of annual income required to meet our objectives was minimized to 0–2.36%. However, in scenarios (excluding scenario 1) in which particular marine sectors were not included in the opportunity cost, it could result in costs up to 11.59% (Table 2). We also found that when a marine sector is

minimized alone (e.g., scenario 2–5), it does not actually benefit (no substantial cost differences) any more than if it were included with other marine sectors in a combined scenario.

We found that spatial conservation priorities selected were sensitive to the different opportunity costs considered (Fig. 3; Appendix C: Figs. C1 and C2). This is also due to the high flexibility of achieving our 10% conservation target in the Mediterranean Sea. In the four combined sector scenarios (scenarios 6 to 9; Fig. 3), we notice that commercial fishing is an important determinant of our spatial priorities due to the selection of similar priority areas for cost layers that used the same commercial fishing cost. Comparing all four combined scenarios (scenarios 6–9), we found that areas that are highly selected in all scenarios are: waters of Malta, coastal waters of western Libya, coastal waters of Egypt, waters of the Adriatic, parts of Greece's EEZ, and waters of France and Monaco. Our Spearman's correlation coefficient showed that there was some correlation between the spatial patterns of the reserve selections. Scenarios with the same commercial fishing surrogate (GFCM or SAUP) were most similar; moreover, scenario 6 was most similar to scenario 8 ($P = 0.97$), and scenario 7 was most similar to scenario 9 ($P = 0.98$). We found that a moderate correlation ($P = 0.52$;
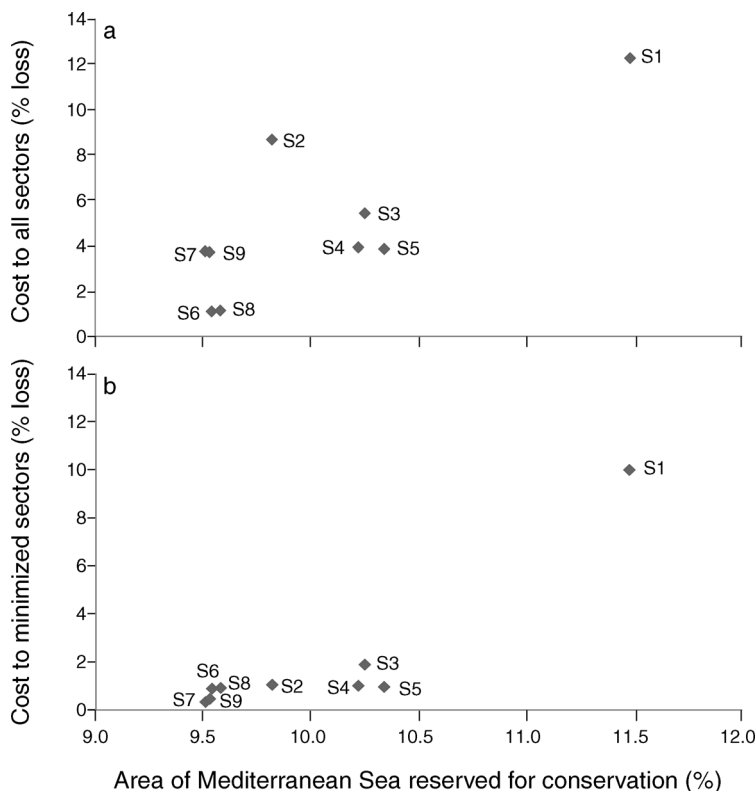

FIG. 2. These graphs compare the cost (percentage of annual loss to marine sectors) and area (percentage of Mediterranean Sea surface area needed to be reserved) to reach our targets for each of our nine scenarios (S1–S9; see Table 1 for a full description of each scenario) of opportunity cost: (a) cost to all sectors vs. area reserved, and (b) cost to minimized sectors vs. area reserved.

a) Scenario 6

b) Scenario 7

Selection frequency (%)

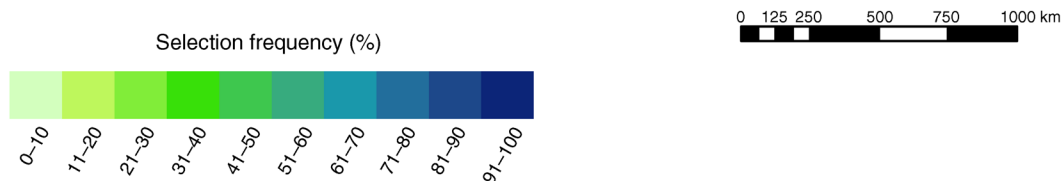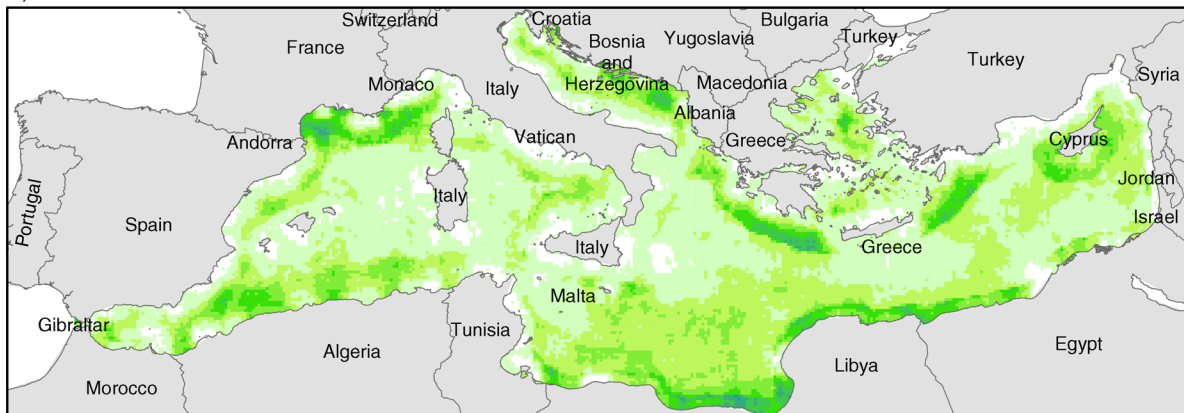0–10 11–20 21–30 31–40 41–50 51–60 61–70 71–80 81–90 91–100
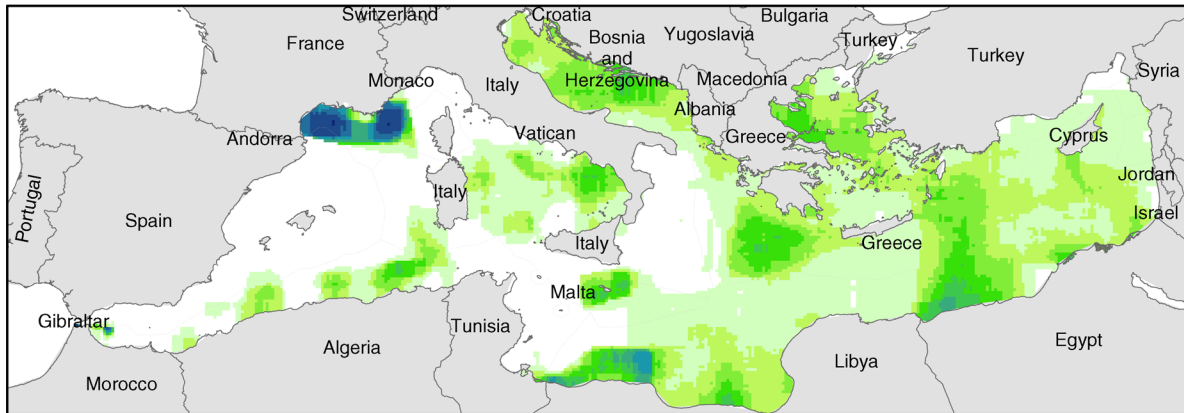
Fig. 3. Selection frequency of four combined fishing layers (combined costs from commercial, noncommercial, and aquaculture sectors) for: (a) combined sectors A (scenario 6), (b) combined sectors B (scenario 7), (c) combined sectors C (scenario 8), (d) combined sectors D (scenario 9). Selection frequency is the percentage of times that an area is selected, from 1000 Marxan runs, as a priority area for conservation as a marine protected area (MPA).

$P = 0.53$) exists between scenarios consisting of different commercial fishing cost layers (Table 3; scenarios 6 and 8, using GFCM, correlated with scenarios 7 and 9, using SAUP). Overall, conservation priorities were largely dominated by the commercial fishing sector (Fig. 3).
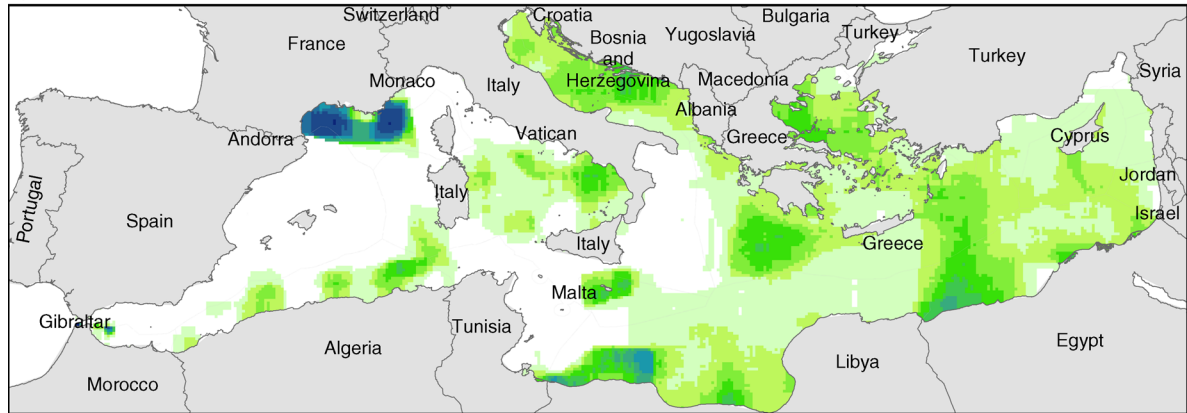
Comparing spatial priorities with consensus areas

We found that some priority conservation areas identified in our study matched with areas found to be consensus areas among multiple conservation plans by Micheli et al. (2013; Fig. 4). When comparing scenario 8 (combined sectors C; Fig. 4b) with the consensus areas (Fig. 4a), we found there was a 25% (37 978.44 km²) overlap of matching priority areas, and an 18% (21 572.78 km²) overlap of priorities with scenario 9

(combined sectors D; Fig. 4c). These matching priority areas include the waters of France and Monaco, parts of the Adriatic Sea, waters of Malta, and coastal areas of western Libya (Fig. 4). Other similarities exist, such as the selection of the Aegean Sea, although Micheli et al. (2013) has priorities in the south of the Aegean Sea (Fig. 4a), whereas our results show priorities in the north of the Aegean Sea as well (Fig. 4b, c).

However, we also identified different priority areas that were not considered priority consensus areas in Micheli et al. (2013). In our study, we identified a large priority area along the coast of Libya and another one that extends from the Egyptian coastline toward the EEZ border with Greece (Fig. 4b, c). Other priorities in our study that were not identified as consensus areas

c) Scenario 8

d) Scenario 9

Selection frequency (%)

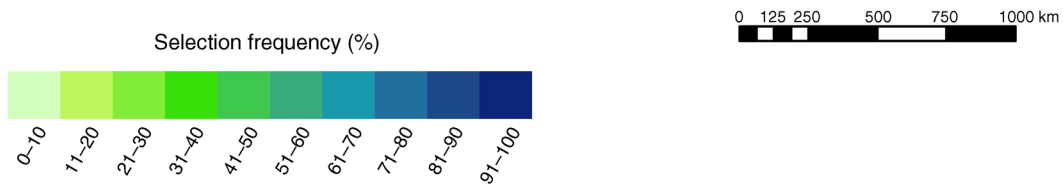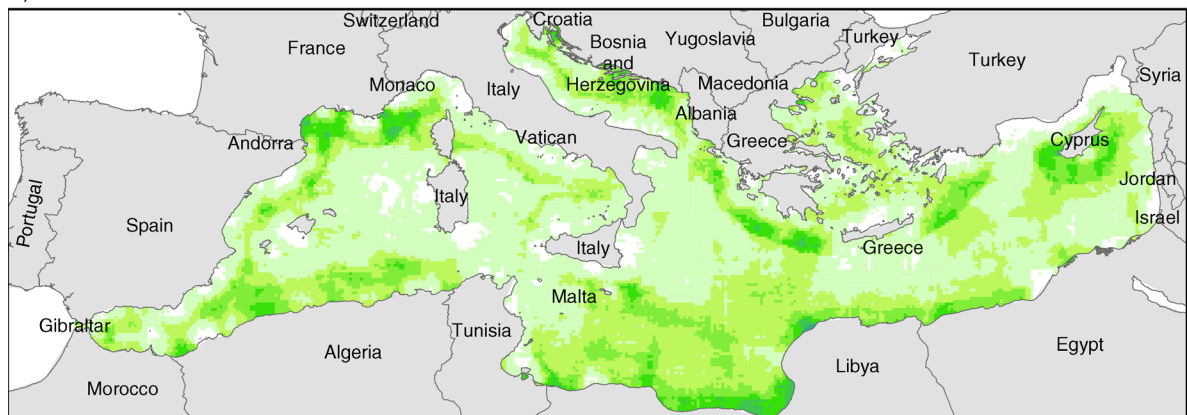0–10 · 11–20 · 21–30 · 31–40 · 41–50 · 51–60 · 61–70 · 71–80 · 81–90 · 91–100

FIG. 3. Continued.

include: parts of Algerian waters, Southern Greece extending toward Egypt, and waters around Cyprus. Our resulting outputs (Fig. 4b, c) show more priority areas within eastern waters of the Mediterranean Sea compared with Micheli et al. (2013), where most are predominantly in the western basin. This is probably due to greater sampling efforts, availability, and accessibility to information on biodiversity and habitats from western areas.

Some consensus areas from Micheli et al. (2013), shown in Fig. 4a, were not present as priority areas in our results (Fig. 4b, c). These areas included most of the Alboran Sea, the Ligurian Sea, and the Tunisian Plateau. The exclusion of such areas in our study is probably due to the high cost associated with these areas, because common species were used within in analysis; the biodiversity features of these areas can be represented (with a target set at 10%) in areas of lower cost.

DISCUSSION

Here, we show that including the cost of implementing marine conservation in the form of opportunity cost, especially within a multinational setting, can greatly influence the selection of priority conservation areas. By using nine different opportunity cost scenarios, we demonstrated how the incorporation of different cost layers can result in spatial conservation plans that have different priority areas (Fig. 3) and different cost and area requirements (Table 2, Fig. 2). The spatial priorities identified in this study met conservation targets while minimizing the opportunity cost for multiple exploitation sectors of marine resources (Fig. 3). In addition, areas considered spatial priorities (e.g., EBSAS [ecolog-

TABLE 3. Spearman rank correlation coefficient of the selection frequency output for each of the combined scenarios. All scenarios show significant $P < 0.001$.

| Scenarios of opportunity cost	Scenario 6	Scenario 7	Scenario 8	Scenario 9
Scenario 6. Combined sectors A (GFCM + noncommercial A + aquaculture)		0.53	0.97	0.53
Scenario 7. Combined sectors B (SAUP + noncommercial A + aquaculture)	0.53		0.52	0.98
Scenario 8. Combined sectors C (GFCM + noncommercial B + aquaculture)	0.97	0.52		0.52
Scenario 9. Combined sectors D (SAUP + noncommercial B + aquaculture)	0.53	0.98	0.52	
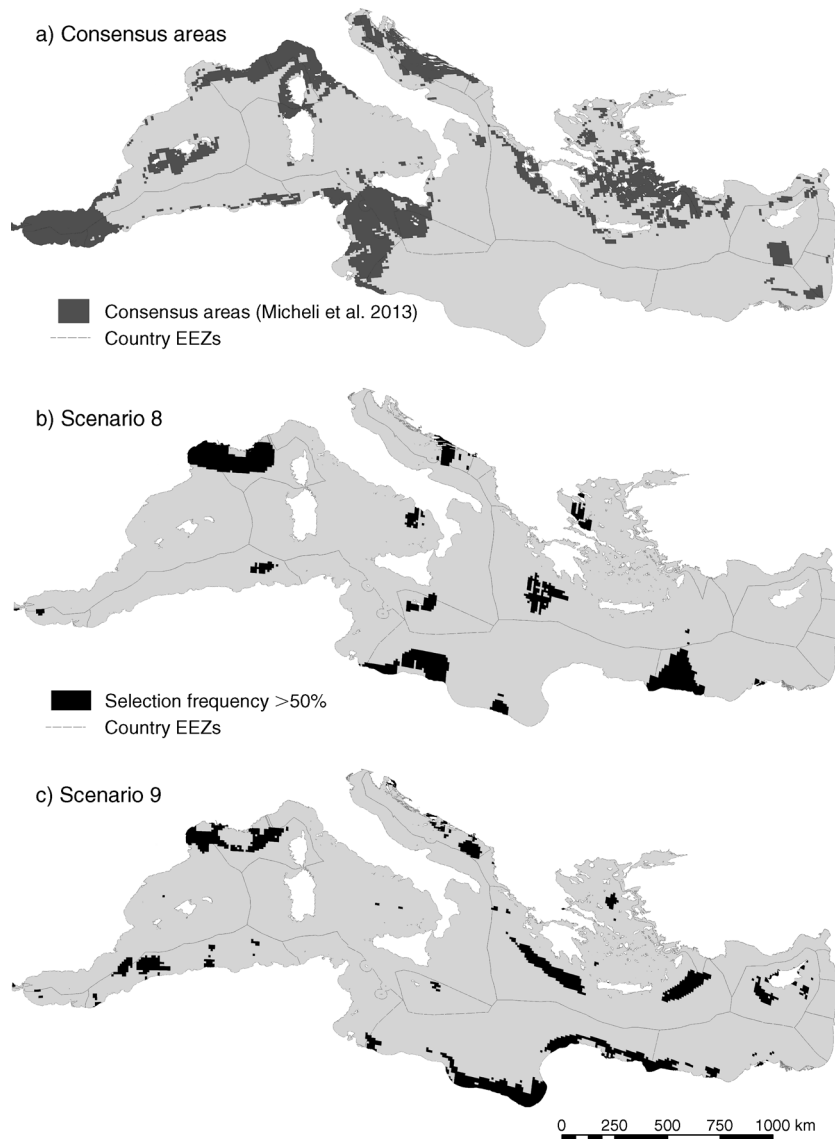
FIG. 4. (a) Consensus areas of prioritization schemes that do not consider costs (dark gray) as presented in Micheli et al. (2013), compared with our resulting priority areas (areas that are selected more than 50% of the time; in black) for (b) combined sectors C (scenario 8), commercial fishing GFCM + noncommercial B ($\alpha = 1.0$) + aquaculture and (c) combined sectors D (scenario 9), commercial fishing SAUP + noncommercial B ($\alpha = 1.0$) + aquaculture. Country EEZ is the Exclusive Economic Zone of each country, with boundaries shown by thin lines in all three panels. SAUP is the Sea Around Us Project (2011); GFCM is the General Fisheries Commission for the Mediterranean (FAO 2011). Refer to Table 1 for full scenario details.

ically or biologically significant marine areas]) by other studies, e.g., the Alboran Sea and the Ligurian Sea, where the Pelagos Sanctuary for marine mammals is located (as identified by WWF [World Wildlife Fund], Greenpeace, and ACCOBAMS [Agreement on the Conservation of Cetaceans of the Black and Mediterranean Seas]; see Micheli et al. 2013) were actually found to be inefficient areas for conservation due to their high cost. Providing conservation plans that fit within economical constraints and budgets is critical for achieving viable conservation outcomes (Naidoo et al. 2006).

We achieved greater conservation efficiency in identifying priority areas for the establishment of MPAs when combining the opportunity cost from different marine sectors (Fig. 2). Moreover, the percentage of cost to the marine sectors and the spatial requirements for an MPA network were reduced. By only accounting for commercial fishing opportunity cost, our results would produce less efficient solutions than combing this cost with opportunity cost for noncommercial fishing and aquaculture. Moreover, planning for a single sector would produce higher costs for other users (Table 2). In the Mediterranean Sea, which is exploited by a composite of marine users from developing and developed nations with diverse socioeconomic, political, and cultural characteristics, it is important that we set multiple objectives when planning conservation to reflect this diversity of marine users. For example, the impact of recreational fishing is often overlooked compared to its counterpart, commercial fishing (Cooke and Cowx 2006). Thus, only considering the cost of commercial fishing when planning conservation may cause our resulting spatial priorities to diverge from ones that are realistically achievable. Not only are there quantifiable benefits (cost and area) but also combining costs from various socioeconomic interests (marine sectors) can build a greater understanding of feasible spatial options that serve multiple objectives rather than encountering future conflicting interests (Cameron et al. 2008, Klein et al. 2008). Providing options that minimize impacts on multiple marine users is pivotal for convincing stakeholders to cooperate in marine conservation and MPA implementation.

Area is a poor cost surrogate in marine systems. In conservation planning, area is sometimes used to represent cost in spatial reserve design (Naidoo et al. 2006). However, monetary costs are considered preferable for decision makers and planners (Naidoo et al. 2006, Carwardine et al. 2008). Nevertheless, in some terrestrial cases it has been suggested that area sometimes may be just as effective as a cost surrogate, or more effective than a poor cost surrogate (Adams et al. 2010). In marine systems, this is not the case. In our study, we see that area as a cost performs poorly at delivering outcomes that minimize the cost for multiple marine sectors (Table 2, Fig. 2). Not only are there less efficient outcomes for marine sectors, but also conser-

vation priorities can be misleading (Ban and Klein 2009). Coastal areas are highly utilized by humans; therefore we know that opportunity cost will be much greater along the coast. This is especially the case in the Mediterranean, where fishing practices are mostly confined to a narrow continental shelf (Papaconstantinou and Farrugio 2000). Similarly, in the Mediterranean Sea the high heterogeneity of wealth and culture between countries means that opportunity costs are far from uniform, which is often considered the case when using area for cost. Although we acknowledge that an inaccurate cost layer will bias results, we emphasize the need for better cost surrogates and approaches for their development and evaluation in the marine realm.

Currently, Mediterranean countries face major economic and political challenges. Cost is an important component of a conservation plan's feasibility, but there are also other issues that determine feasibility, e.g., law enforcement in territorial waters where priority areas have been identified. In the Mediterranean Sea, some countries in the northern part of the basin are on the verge of bankruptcy and those in the east and south are experiencing societal instability and shifts in political regimes (Gaiser and Hribar 2012). As a result, resources for conservation are more limited than ever and wise decisions should be made for their allocation. We propose that future conservation plans for the Mediterranean Sea apply systematic plans where costs and benefits can be explicitly estimated and, hence, can appropriately guide decision-making. Moreover, spatial priorities should be coupled with specific conservation actions and return on investment should be estimated to facilitate informed decision-making.

The surrogates provided in this study indicate the lack of knowledge and comparable data we have when planning large-scale marine areas that span multiple countries. In areas that encompass several countries with great economic, political, and cultural heterogeneity, it becomes difficult to find data that are in a compatible format, are spatially refined, temporally comparable or that even exist. We have attempted to keep data temporally consistent where possible, and to account for the variance between countries using PPP adjustment in our cost metrics. However, the ability to validate our surrogates is impossible with the lack of detailed information on commercial and noncommercial fishing in the Mediterranean Sea. Although it may be argued that our results are based on coarse surrogate data, previous studies in terrestrial landscapes (Ando et al. 1998, Moore et al. 2004) and small-scale marine settings (Stewart and Possingham 2005) show that the use of opportunity cost data can substantially improve efficiency in selecting priority conservation areas beyond a study that used area as a cost factor or completely ignored cost. Distance from port or coast is a representative measure of fishing pressure according to numerous studies, especially for small-scale fishing (Cabrera and Omar 1997, Caddy and Carocci 1999,

Gelchu and Pauly 2007, Stelzenmüller et al. 2008). Moreover, some studies have applied it to prioritization schemes (Sala et al. 2002, Stewart et al. 2010, Giakoumi et al. 2011) and it has been proven to perform well in comparison to other cost surrogates, e.g., population pressure (Weeks et al. 2010). However, we acknowledge that large-scale fishing, mainly industrial fishing, is driven by specific features, e.g., the migratory paths of commercial pelagic species. The availability of data on Vessel Monitoring Systems applied in large-scale fisheries in most Mediterranean countries could improve the estimation of the spatial distribution of such commercial fisheries (Maiorano et al. 2009, Giakoumi et al. 2012a). We propose that future studies address these shortages of data in the Mediterranean Sea, and as information and data become readily available, our priorities can be validated and appropriately adjusted.

Our approach for large-scale conservation planning provides a platform for future expansion. This includes other types of cost involved with implementing an MPA network. These costs specifically include: monitoring cost, transaction cost, and management cost. Future considerations should include issues such as illegal fishing, political stability, variation in law enforcement among countries, and the ability for countries to collaborate (Levin et al. 2013). Our study used coarse species distribution data from the IUCN (2012); however, building a better database of species and habitat distribution for the Mediterranean Sea, which is consistent between countries and at a finer spatial resolution, will help to better determine spatial priorities that reach conservation targets.

This work contributes to and builds upon a growing body of literature (see Naidoo et al. 2006, Bode et al. 2008, Ban et al. 2009) that demonstrates the benefits of including cost when planning conservation. Moreover, our findings support evidence from previous studies showing that the identification of priority areas is more sensitive to the inclusion of cost data than biodiversity data, highlighting the necessity to consider both ecological and economic data in prioritization schemes (Bode et al. 2008). We demonstrated that priority areas for conservation can be selected to be spatially compatible with multiple sectors of marine users, even in a data-poor system. Our approach is also relevant and applicable to other marine regions that are shared between various geographic jurisdictions such as states, territories, or countries (e.g., the Black Sea, the Gulf of Mexico, the Baltic Sea, the Caribbean Sea). Overall, the inclusion of cost when setting spatial conservation priorities can help to provide better investment decisions and advance conservation efforts in a timely and efficient manner.

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SUPPLEMENTAL MATERIAL

Appendix A

Detailed information of threatened species used in this study (*Ecological Archives* A024-064-A1).

Appendix B

Detailed descriptions of input data and resulting cost layers (*Ecological Archives* A024-064-A2).

Appendix C

Results of 30% target and selection frequency outputs from Marxan analysis (*Ecological Archives* A024-064-A3).